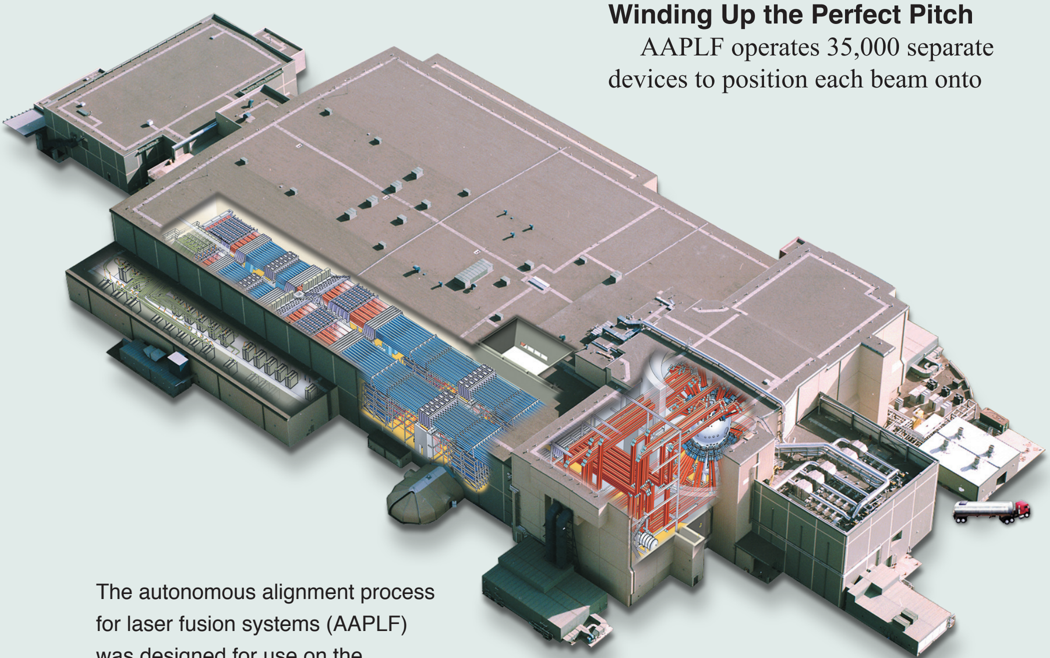
Automated Technology for Laser Fusion Systems

THE day is fast approaching when Lawrence Livermore's National Ignition Facility (NIF) will conduct experiments to achieve controlled fusion reactions in a laboratory setting. The success of these experiments relies on the precise alignment of NIF's 192 laser beams, which will direct light down a 300-meter optical path onto a cylindrical target a few millimeters in diameter—slightly larger than the head of a pushpin.

Laser systems typically use manual or semiautomated processes to adjust optics and configure beamlines. Manual operations can be unreliable or imprecise. Semiautomated methods work well only under optimal conditions, for example, when beam quality is unaffected by noise or other external influences.

A completely autonomous alignment process developed by a team of Livermore researchers eliminates human error while effectively aligning the beams with high accuracy in less than 15 minutes. In developing the autonomous alignment process for laser fusion systems (AAPLF, pronounced apple-f), the Livermore team received a 2008 R&D 100 Award. AAPLF not only performs the optical adjustments for each beamline, but it also directs the focused beams to the target, where they produce the extremely high temperatures and pressures needed for fusion experiments.



The autonomous alignment process for laser fusion systems (AAPLF) was designed for use on the National Ignition Facility.

Winding Up the Perfect Pitch

AAPLF operates 35,000 separate devices to position each beam onto the NIF target within a tolerance of 10 micrometers. Aligning the beams within such a small margin of error is analogous to hitting a baseball strike zone with a pitch thrown from approximately 560 kilometers away. To make this perfect pitch possible, AAPLF analyzes images of each beam and adjusts the optics as needed. It begins by retrieving the alignment plans for an experiment from a database. The beams, which are grouped into 24 bundles of eight, are sampled from within the NIF subsystems, such as the Preamplifier Modules (PAMs), in ways that do not interfere with normal beam operations.

The software "brain" of AAPLF, called the Segment Manager, coordinates other parts of the control system, including the Components Manager and Image-Processing Cluster, to configure the beamlines, capture the necessary images, and execute image-processing algorithms. The Components Manager processes requests from the Segment Manager to use devices, such as actuators and cameras, that are shared between beams within the system. It places requests in a queue and blocks access to devices already in use. Once a device becomes available, the Segment Manager can use it to adjust mirrors and beam optics. Adjustments are executed by 26 control loops that center and point each beam down its respective path. The Segment Manager then acquires another set of images to determine if further changes are necessary.

AAPLF uses masks as passive references to locate a beam's position within a PAM. Masks are made from transparent glass plates that contain two types of markings, called fiducials. An initial mask adds fiducials to the beam, while downstream masks with different fiducials define desired beam positions. Mirrors reflect the laser beams onto these reference fiducials, and a video-camera sensor records images of a beam passing through each downstream mask. Image-processing algorithms then determine how far the laser beam is from the reference position. If the reference and laser beam locations do not match, AAPLF adjusts the optics and repeats the process until the beam is properly aligned.

During the alignment process, sensors acquire images from different areas, such as NIF's target chamber or PAMs. A suite of 22 image-processing algorithms analyzes the images to determine the beam positions. The algorithms also process complex images that would be difficult or impossible for an operator to accurately interpret. Conditions within the laser system can cause artifacts such as diffraction and noise to appear in the images. AAPLF algorithms mitigate these effects and determine if a system problem exists that needs attention.

AAPLF development team: (back row, from left) Wilbert McClay, James Candy, Christopher Estes, Lawrence Lagin, David McGuigan, Erlan Bliss, Sean Lehman, Abdul Awwal, Haiyan Zhang, and Suzanna Townsend; (middle row) Paul Van Arsdall, Charles Orth, Thad Salmon, Scott Burkhart, Allan Casey, and Charles Reynolds; (front row) Roger Lowe-Webb, Robert Carey, Ben Horowitz, Mark Bowers, Michael Flegel, Mark Miller, Walter Ferguson, Eric Stout, Karl Wilhelmsen, Victoria Miller Kamm, and Richard R. Leach, Jr. Not pictured: Stephanie Daveler, Holger Jones, and Karl Pletcher.

Endless Possibilities

AAPLF is an accurate, reliable, and effective method for precisely aligning NIF's complex laser system. "The AAPLF computer controls and parallel image-processing systems are teamed with sophisticated yet highly multiplexed sources and references to create a powerful, autonomous process," says Scott Burkhart, a laser engineer who monitors AAPLF from the control room. "Without this system, we could not achieve the precision needed for laser fusion." AAPLF has performed successfully in more than 1,200 system and 30,000 preamplifier beam shots. In addition, the system can be scaled to any number of laser beams and thus can be adapted for the laser fusion systems of the future.

With the AAPLF beam-alignment system, NIF will soon begin experiments to achieve fusion ignition and burn in a laboratory setting. "NIF will provide critical support for Livermore's national security missions," says Ed Moses, principal associate director for NIF and Photon Science. "It also opens up exciting opportunities to explore the high-energy-density physics of the cosmos and to develop an essentially inexhaustible supply of clean energy. Innovations like AAPLF are the hallmark of what makes our Laboratory great."

—Caryn Meissner

Key Words: autonomous alignment process for laser fusion systems (AAPLF), fusion, image-processing algorithm, laser beam path, National Ignition Facility (NIF), photon science, R&D 100 Award.

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